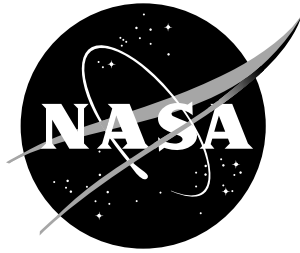


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TBIEM3D - A Computer Program for Predicting Ducted Fan Engine Noise

Version 1.1

M. H. Dunn

September 1997

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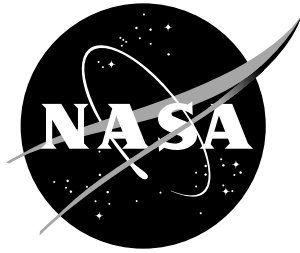
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TBIEM3D - A Computer Program for Predicting Ducted Fan Engine Noise

Version 1.1

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List of Symbols

a	axial coordinate of duct trailing edge in moving frame
b	axial coordinate of duct leading edge in moving frame
c	ambient sound speed
k	nondimensional characteristic wave number
L_D	ratio of duct length to diameter
m	harmonic number
M	$= V/c$ flight Mach number
M_{TIP}	$= r_D \Omega/c$ tip Mach number (based on duct radius)
N_B	number of point dipoles
N_L	number of liner segments
N_{OBS}	number of observers for TBIEM3D output
P	total acoustic pressure
P^m	m -th coefficient of total pressure
P_i	incident acoustic pressure
P_i^m	m -th coefficient of incident pressure
P_s	scattered acoustic pressure
P_s^m	m -th coefficient of scattered pressure
(r, ψ, Z)	cylindrical coordinates in frame of reference attached to duct
r_D	duct radius
r_0	radial coordinate of spinning point dipoles
t	time
T	thrust from fan

V	duct speed
$\{Z_j\}_{j=1}^{N_L+1}$	axial locations of liner segments
$\alpha(Z)$	$= \rho_0 c [\xi(Z) - i\sigma(Z)]$ segmented, specific acoustic admittance on interior duct wall
$\{\alpha_j\}_{j=1}^{N_L}$	piecewise specific acoustic admittances
β	$= \sqrt{1 - M^2}$ compressibility (stretching) parameter
κ	$= k/\beta$ nondimensional stretched characteristic wave number
ρ_0	ambient density
$\sigma(Z)$	segmented, acoustic susceptance on interior duct wall
$\xi(Z)$	segmented, acoustic conductance on interior duct wall
ω	frequency of oscillations (radians/second) for nonspinning dipoles
Ω	shaft speed (radians/second) for spinning dipoles

Introduction

This document describes the ducted fan noise prediction computer program TBIEM3D (Thin duct, Boundary Integral Equation Method, 3 Dimensional). The scattering of fan generated noise by a finite length, infinitesimally thin circular cylinder in a uniform flow field is considered. The program, based on a boundary integral equation method (BIEM), calculates circumferential modal coefficients of the acoustic pressure at user specified field locations. TBIEM3D features include versatility, rapid calculations, and ease of use. Theoretical and computational details can be found in references 1-4.

In a frame of reference attached to the duct, the fan generates spinning acoustic modes. The thrust component of fan loading noise is approximated by a collection of spinning point thrust dipoles. A precise mathematical representation for the acoustic field due to this configuration has been implemented.

TBIEM3D employs cylindrical coordinates in a frame of reference attached to the engine (figures 1-3). The coordinate origin is at the center of the fan disc. The fan and duct translate in the +Z (axial) direction with uniform speed V . N_B equally spaced blades comprise the fan. The shaft rotates with speed Ω (figure 2).

The total acoustic pressure in the sound field is split into known incident and unknown scattered parts:

$$P'(r, \psi, Z, t) = P'_s(r, \psi, Z, t) + P'_i(r, \psi, Z, t) \quad . \quad (1)$$

Assuming linear conditions, all dependent acoustic variables can be expressed as superpositions of spinning modes. For example, the scattered pressure has the form

$$P'_s(r, \psi, Z, t) = \sum_{m=-\infty}^{\infty} P_s^m(r, Z) e^{imN_B(\Omega t - \psi)} \quad . \quad (2a)$$

Incident and total acoustic pressures are written similarly. Modal amplitudes are calculated term by term. The TBIEM3D code must be run separately for each desired mode.

For some applications, the propagation of a plane wave through the duct is of interest. The spinning point source model is incapable of producing the plane wave. If nonspinning sources are used, then all

components of the acoustic field have the form

$$P'(r, \psi, Z, t) = e^{i\omega t} \sum_{m=-\infty}^{\infty} P^m(r, Z) e^{-imN_B \psi} \quad (2b)$$

The modal function $P^0(r, Z)$ contains plane wave information (see Example 4).

In TBIEM3D, the point thrust dipole sources may be spinning or nonspinning. The nonspinning source configuration could be used to model stators and is useful in examining some aspects of duct radiation and propagation.

The duct exterior is hard and the interior may be hard or lined. The duct liner is modeled by an axisymmetric, locally reactive, segmented liner with user specified admittances. The definition of specific acoustic admittance used by TBIEM3D

$$\alpha(Z) = \rho_0 c [\xi(Z) - i\sigma(Z)] \quad (3)$$

is consistent with the time factor $e^{+imN_B \Omega t}$ in (2). Regions of the duct interior near the leading and trailing edges are assumed hard (figure 3). Any interior wall segment may also be rigid. These comments are summarized by the equation

$$\alpha(Z) = \begin{cases} 0 & Z \in [a, Z_I] \cup [Z_{N_L+1}, b] \\ \alpha_i & Z \in (Z_j, Z_{j+1}) \quad j = 1, \dots, N_L \end{cases} \quad (4)$$

BIEM methodology is a three step process: Step 1) A Helmholtz boundary value problem (BVP) for the modal coefficients in (2) is derived. Step 2) Using layered Helmholtz potentials, the BVP is converted to a boundary integral equation formulation that features a set of hypersingular integral equations for the unknown Helmholtz layers. Step 3) The integral equations are solved and the acoustic field calculated from the Helmholtz potential representation.

The TBIEM3D code is written in the FORTRAN programming language and employs IMSL mathematical library routines. TBIEM3D should be implementable on any computer that can accommodate FORTRAN and IMSL. Some code modification may be required. For minimally adequate

computational performance, a Pentium 133 processor (or equivalent) with 32 megabytes of RAM is recommended.

TBIEM3D input is relatively simple. Geometric, kinematic, and liner parameters are required. If a source description other than the one described above is desired, then the user must supply FORTRAN subroutines for the calculation of the incident field and its radial derivative. Output from TBIEM3D consists of the modal coefficients of the complex pressure components [see equations (1-2)] at user specified field points. Postprocessing of results is left to the user.

The key feature of TBIEM3D is the ability to compute any portion of the sound field without the need to calculate the entire field. Competing methods such as finite differences and finite elements lack this property. Other positive attributes include reduced consumption of computational resources, enhanced numerical accuracy, versatility, coupling of radiation and propagation both forward and aft, and validity over a wide range of frequencies. Consequently, the TBIEM3D code is well suited for parametric calculations. Many engineering studies of interest can be handled by TBIEM3D.

Questions, comments, and requests for discussions should be addressed to **mhd314@aol.com**

Limitations

- 1) At present, the TBIEM3D code can treat “small” Mach number inflow. Results obtained for $M > 0.4$ may be questionable. TBIEM3D with no inflow restrictions will be made available when complete.
- 2) For large values of κ , TBIEM3D computational time and storage requirements can increase considerably. Therefore, at typical fan operating conditions, it is recommended that the user calculate a maximum of three circumferential modes. Efforts are underway to improve TBIEM3D performance for high frequencies.
- 3) It is well known from the theory of wave propagation in an infinite, hard walled duct that resonance occurs at certain discrete frequencies. At these eigenfrequencies, the infinite duct problem is unsolvable. Theoretically, the finite, hard walled interior duct is solvable at all frequencies. Ill-conditioning in the TBIEM3D numerical system, however, is experienced at and near the infinite duct eigenfrequencies. TBIEM3D results at these eigenfrequencies show evidence of resonance but appear plausible. The numerical correctness of TBIEM3D at resonance has not been established. Therefore users should examine TBIEM3D results carefully when the hard wall interior option is activated.
- 4) For some applications, it may be convenient to place the sources outside the duct. This is easily achieved with TBIEM3D. The user must have either $a > 0$, $b < 0$, and/or $r_o > r_D$.
- 5) Since the duct is approximated by an infinitely thin cylinder, the acoustic pressure is discontinuous across the duct surface. Consequently, evaluation of the acoustic pressure on the duct wall is ambiguous. It is recommended that if the pressure on the interior duct surface is required, then the user should place the observer a small distance off the duct toward the interior.

- 6) If the nonspinning point dipole option is activated ($k_{spin} = 0$), then several TBIEM3D input parameters assume different meanings: 1) N_B = number of nonspinning dipoles; 2) T = arbitrary source strength in Newtons which need not correspond to the fan thrust; 3) $RPM = (30\omega)/\pi$ (shaft RPM is meaningless in this context)
- 7) The spinning point thrust dipole configuration yields a simplified approximation for the thrust component of the fan loading noise. As a result, the user may need to experiment with the radial location of the source and the source strength to obtain meaningful quantitative results.
- 8) Other sources of fan noise such as thickness and the drag component of loading are not included in this version of TBIEM3D. Future versions will include point and/or line source modeling of these phenomena. The capability to predict rotor/stator interaction is also being considered for future release.

Operating Instructions

TBIEM3D operating parameters consist of a one line identifier, output file name and path, and physical parameters. The code generates one output file containing values of program parameters and the complex modal coefficients of incident, scattered, and total pressure at user specified field points. The output file is associated with logical unit 9. Access of unit 9 elsewhere in the calling program can lead to errors and should be avoided. COMMON statements in TBIEM3D should be examined to avoid conflicts with the user program.

To activate TBIEM3D, the user's calling program must have the FORTRAN statement

$$\begin{aligned} & \text{CALL TBIEM3D}(kspin, ident, outfile, m, N_B, RPM, r_D, a, b, r_0, T, c, \rho_0, V, \quad (5) \\ * & \quad N_L, \{Z_j\}_{j=1}^{N_{L+1}}, \{\alpha_j\}_{j=1}^{N_L}, N_{OBS}, \{\bar{Z}_j\}_{j=1}^{N_{OBS}}, \{r_j\}_{j=1}^{N_{OBS}} \quad) \end{aligned}$$

The notation $\{x_j\}_{j=1}^N$ in (5) denotes a one dimensional array of length N . Variables in the argument list are described in table 1. SI units are required for dimensional variables.

The TBIEM3D output file contains the case identifier and program parameters followed by N_{OBS} formatted lines containing the dimensional (pascals) complex modal coefficients of incident, scattered, and total acoustic pressure. For each observer point, TBIEM3D writes the observer coordinates and pressure components according to the following FORTRAN statements:

```

WRITE(9,600) Z, r, Re[Pim], Im[Pim], Re[Psm], Im[Psm], Re[Pm], Im[Pm]
600    FORMAT(8E11.4) .

```

Examples

Three examples are presented in this section to demonstrate TBIEM3D features and usage with spinning point dipole sources. Kinematic parameters were chosen to simulate actual ducted fan engine operating conditions ($M_F = 0.40$, $M_{TIP} = 1.22$, $N_B = 20$, $L_D = 0.50$). The examples differ in the acoustic treatment on the duct interior. Admittances for the three cases are given below. All calculations were performed on a Pentium 133 laptop computer with 32 megabytes of RAM. Graphical results displayed here are not part of TBIEM3D.

For each of the three cases, continuous two dimensional portions of the sound field are computed. Acoustic pressure and sound pressure level contours for the first harmonic ($m = 1$) are plotted in figures 5-7. The specific acoustic admittances used for the calculations do not necessarily correspond to actual conditions but were chosen for demonstrative purposes. Figure 4 contains the FORTRAN calling program that generated the results for figures 5-7.

Example 1 Hard inlet and hard exhaust. See figure 5. Four minutes computational time required for 15000 field points.

$$\text{Admittance: } \alpha(Z) = 0 \quad Z \in [a, b]$$

Example 2 Lined inlet (one segment) and hard exhaust. See figure 6. Eight minutes computational time required for 15000 field points.

$$\text{Admittance: } \alpha(Z) = \begin{cases} 1-i & Z \in (0, 0.4) \\ 0 & \text{elsewhere} \end{cases}$$

Example 3 Lined inlet (one segment) and lined exhaust (one segment). See figure 7. Eight minutes computational time required for 15000 field points.

$$\text{Admittance: } \alpha(Z) = \begin{cases} 1-i & Z \in (0, 0.4) \\ 0.5 & Z \in (-0.4, 0) \\ 0 & \text{elsewhere} \end{cases}$$

In figure 8, comparisons between the three cases in both the nearfield and farfield are displayed. Sound pressure levels for the first modal coefficient on an arc of 200 field points about the duct center are calculated. The radius of the arc is ten meters for the farfield example and one meter for the nearfield example. The arc extends from the forward duct axis to the aft duct axis. The results are plotted to show the effects of liner treatment. Calculations required approximately one minute.

Example 4 was designed to simulate a no inflow, open ended impedance tube experiment. Twenty nonspinning point dipoles were placed near the left end of a three meter long tube of radius 2.54 cm. A one meter long liner specimen with specific acoustic admittance $2.2 + 0.2i$ was placed in the center of the tube. The remainder of the tube was unlined. The source frequency was 900 Hz and the zero-th harmonic was examined. For these parameters only the plane wave propagates in the unlined portions of the tube.

The complex acoustic pressure for a line of observers at $r = 2.0$ cm extending along the length of the tube was calculated. In figure 9, the amplitude (in decibels) and phase of the complex pressure is plotted as a function of distance along the tube. There is approximately a 40 dB drop in sound pressure level along the lined section. The complex wave structure in the right end of the tube is due to reflection from the open end.

References

- [1] M.H. Dunn, J. Tweed, and F. Farassat: The Prediction of Ducted Fan Engine Noise Via a Boundary Integral Equation Method; AIAA Paper 96-1770; Dunn, Tweed, and Farassat, April 1996.
- [2] M.H. Dunn, J. Tweed, and F. Farassat: The Prediction of Radiated Tonal Noise from an Acoustically Treated Engine Duct; To be submitted to the Journal of Sound and Vibration.
- [3] R. St. John, M.H. Dunn, and J. Tweed: Acoustic Scattering Problems in Two Dimensions; Paper to be presented at the 4th AIAA/CEAS Aeroacoustics Conference, June 2-4, 1998, Toulouse, France.
- [4] J. Tweed, M.H. Dunn, and R. St. John: On the convergence of Algorithms for the Numerical Solution of a Finite-Part Integral Equation; To be submitted to the Journal of Integral Equations.

Variable	Description	Comments
$kspin$	Integer; source parameter; $kspin = 1$ implies spinning sources; $kspin = 0$ implies nonspinning sources	see limitation 6
$ident$	Character*80 variable; case identifier	80 ASCII characters maximum
$outfile$	Character*80 variable; output file name	80 ASCII characters maximum; file path may be included
m	Integer; Harmonic number	See (2) and limitation 2
N_B	Integer; Number of fan blades	See figures 1-3; $N_B > 0$; see limitation 6
RPM	Real; shaft speed (revolutions per minute)	$\Omega = (\pi RPM)/30$; see limitation 6
r_D	Real; duct radius (meters)	See figures 1-3
a	Real; axial coordinate of duct trailing edge (meters)	See figures 1-2
b	Real; axial coordinate of duct leading edge (meters)	See figures 1-2
r_0	Real; radial location of spinning dipoles (meters)	See figures 2-3; see limitation 7
T	Real; thrust from fan (kilonewtons)	see limitation 6
c	Real; Ambient sound speed (meters per second)	
ρ_0	Real; Ambient density (kilograms per cubic meter)	
V	Real; Engine speed (meters per second)	$V/c < 1$; see limitation 1
N_L	Integer; number of liner segments	For hard wall interior set $N_L = 0$ in which case limitation 3) may apply
$\{Z_j\}_I^{N_L+1}$	Real; axial coordinates of liner segments (meters)	See (3-4) and figure 3; if $N_L = 0$, then omit; $a < Z_i < Z_{i+1} < b \quad i = 1, \dots, N_L$
$\{\alpha_j\}_I^{N_L}$	Complex; acoustic admittances (non dimensional) for segmented liner	See (3-4) and figure 3; if $N_L = 0$, then omit; some segments may be hard, i.e., $\alpha_i = 0$
N_{OBS}	Integer; number of observers for output	$0 < N_{OBS} \leq 10^5$; Large values of N_{OBS} can lead to excessive computational time
$\{\bar{Z}_j\}_I^{N_{OBS}}$	Real; axial coordinates of observer points (meters)	See limitation 5
$\{r_j\}_I^{N_{OBS}}$	Real; radial coordinates of observer points (meters)	

Table 1: TBIEM3D Input Parameters

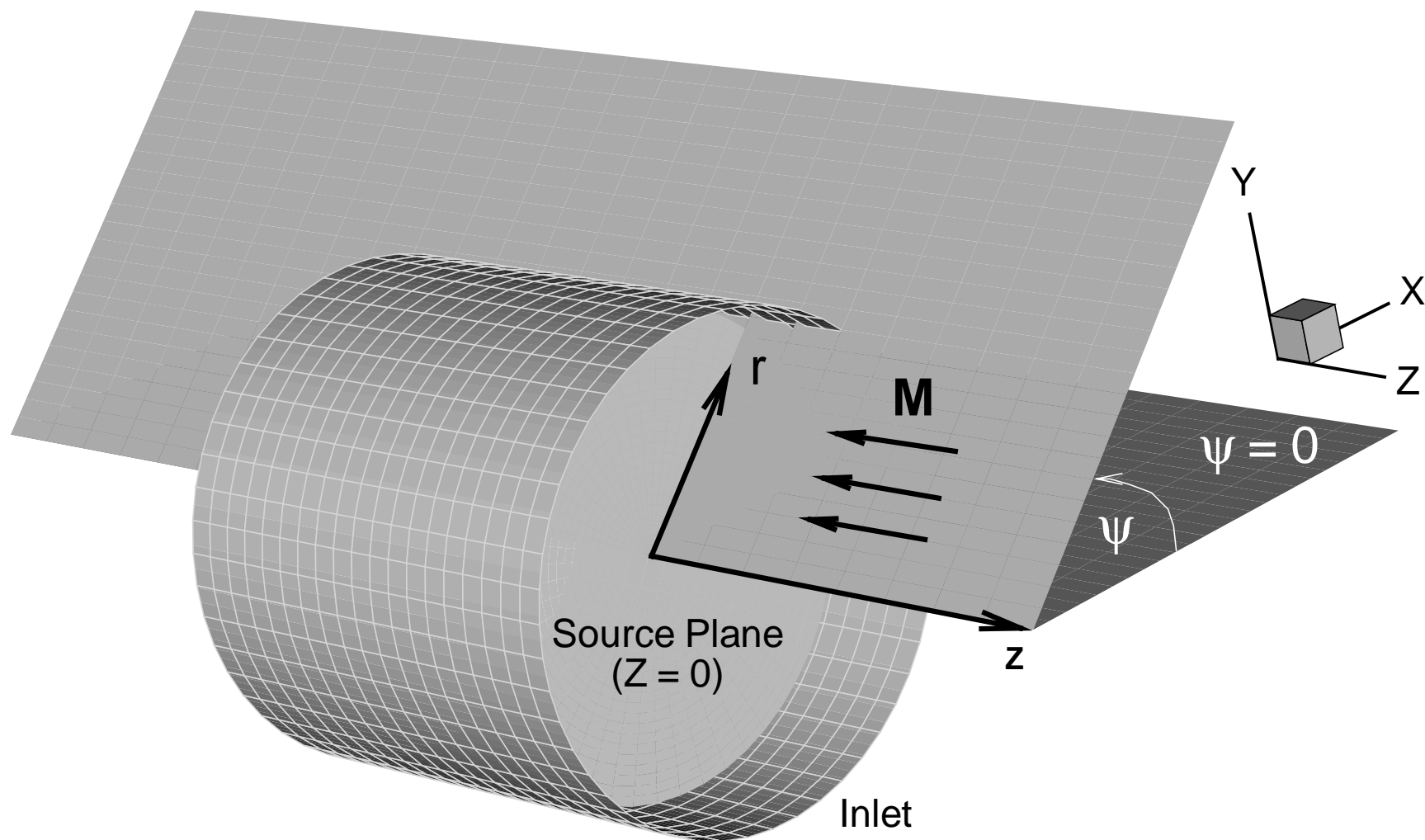


Figure 1: Duct Geometry and Coordinate Definitions
Cylindrical Frame Fixed to Duct

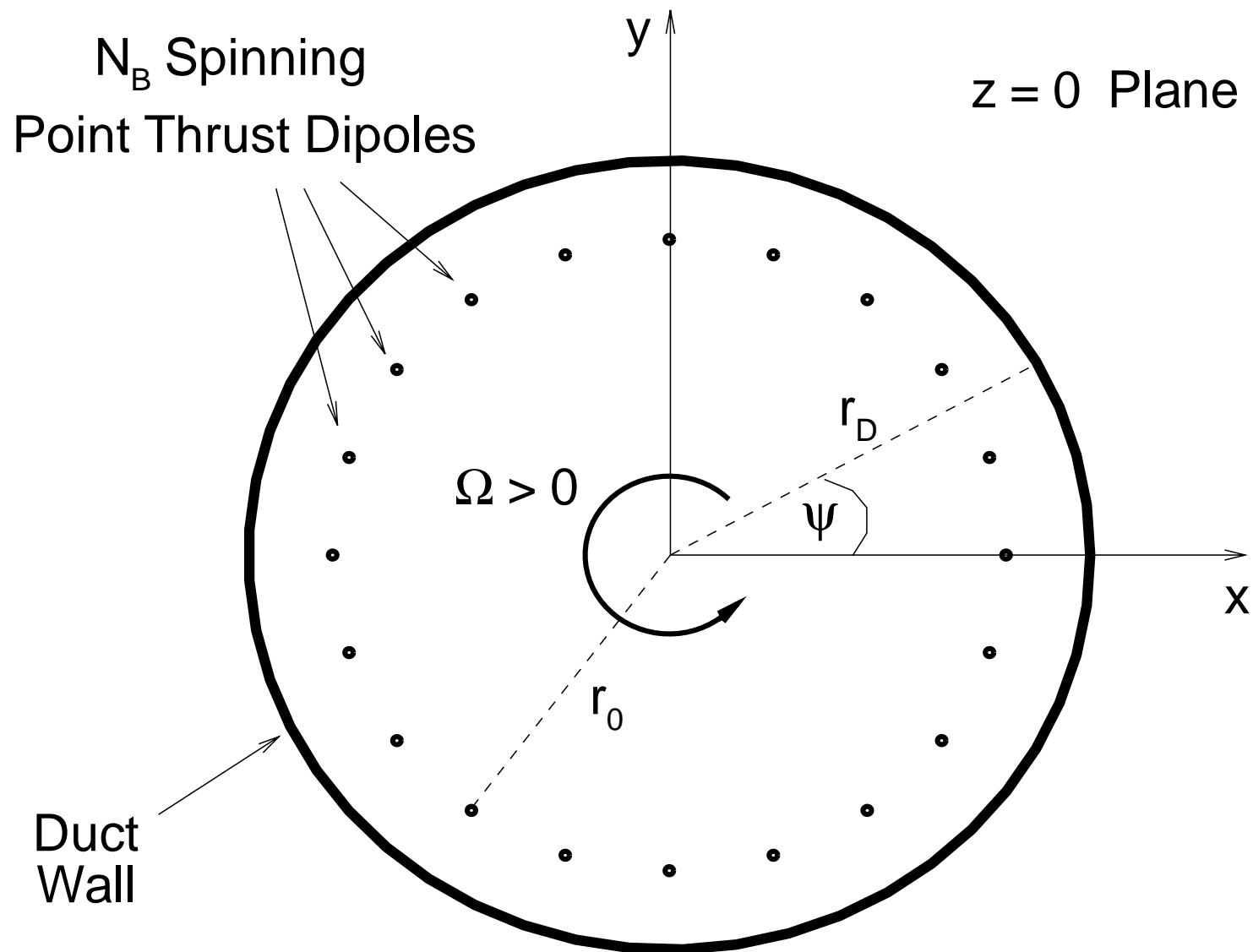


Figure 2: Source Plane Geometry
 View from Inlet into Duct

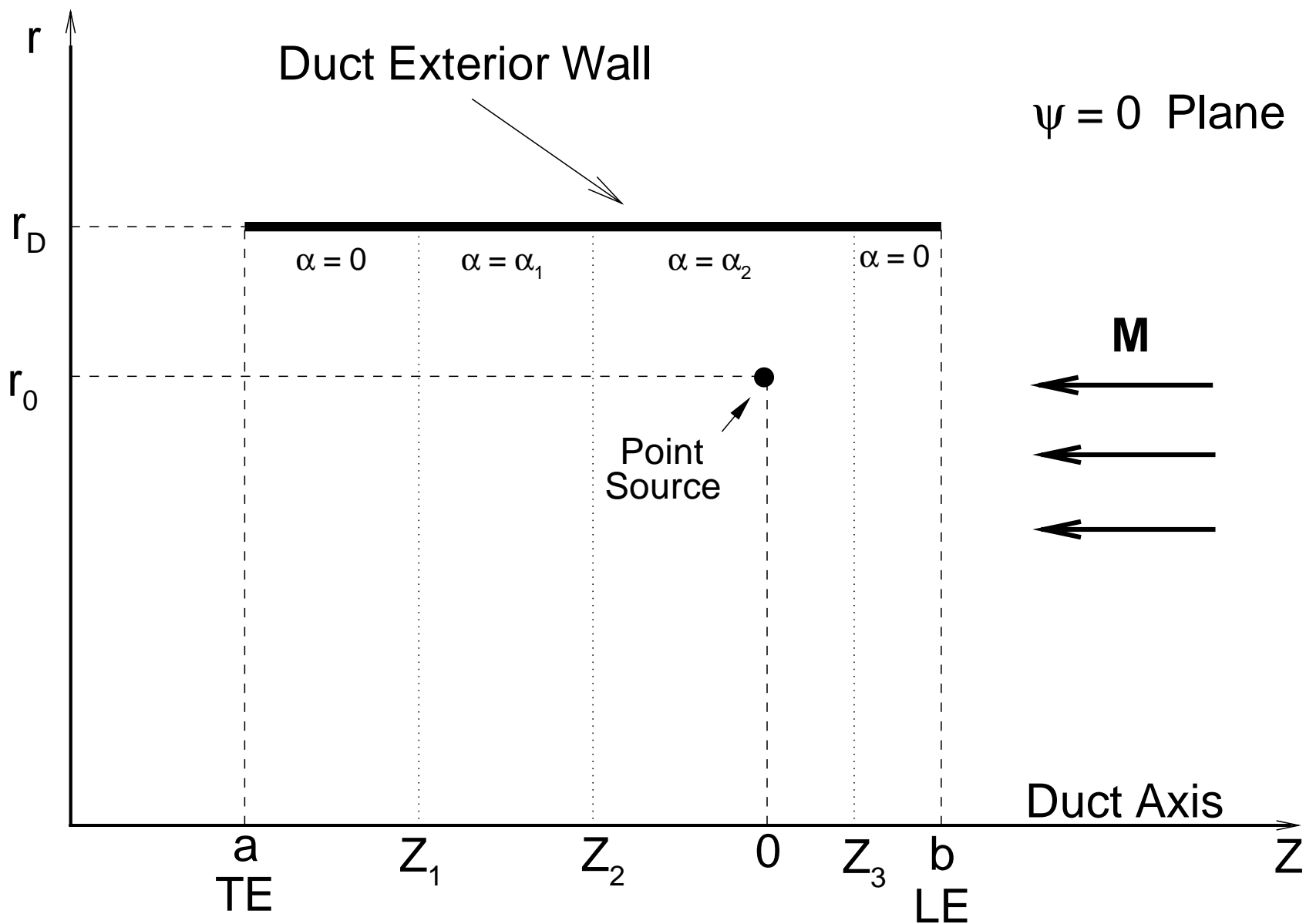


Figure 3: Duct and Liner Geometry (Side View)
Two Piece Segmented Liner

```

c
c+++++
c Calling Program for Examples 1-3 (Figures 5-7) in User
c Document - This is a sample calling program and is not part of
c TBIEM3D
c+++++
c
      program myBIEM
      dimension ZOBS(100000),rOBS(100000),Zliner(100)
      complex admit(100)
      character*80 ident,outfile,outfx
c
c-----
c Set up TBIEM3D geometric and kinematic input parameters
c-----
c
      ident = 'TBIEM3D Figures 5-7 (see User Document)'
      outfile = 'c:\xxx1.txt'
      outfx = 'c:\figs5-7.dat'
      pref = 2.*10.**(-5.)
      nharm = 1
      nblades = 20
      rpm = 3500.
      radiusd = 1.0
      zte = -0.50
      zle = 0.50
      radius0 = 0.90
      thrustc = 1.
      sposnd = 300.
      density = 0.4
      V = 120.
      kspin = 1
c
c-----
c Input observer points for 2-D field      calculations
c-----
c
      nz = 150
      nr = 100
      NOBS = nz*nr
      zmin = -2.
      zmax = 2.
      dz = (zmax-zmin)/float(nz-1)
      rmin = 0.
      rmax = 3.
      if(nr.ne.1)then
         dr = (rmax-rmin)/float(nr-1)
      else
         dr = 0.
      endif
      kount = 0
      do i = 1,nz
         z = zmin+(i-1.)*dz
         do j = 1,nr
            kount = kount+1
            r = rmin+(j-1.)*dr
            ZOBS(kount) = z
            rOBS(kount) = r
         enddo
      enddo

```

Figure 4: Calling Program for TBIEM3D Examples 1-3

```

C
C-----
C Example 1: Hard Wall Interior
C-----
C
      NL = 0
      call TBIEM3D(kspin,ident,outfile,nharm,nblades,rpm,radiusd,
1          zte,zle,radius0,thrustc,sposnd,density,V,NL,
2          Zliner,admit,NOBS,ZOBS,rOBS)
C
C*****
C Begin output for user document graphics
C*****
C
      open(unit=10,file=outfx,status='unknown')
      write(10,*)'zone t = "1", i = ',nr,', j = ',nz
      rewind(9)
      do j = 1,19
          read(9,*)
          enddo
      do iobs = 1,NOBS
          read(9,600)zz,rr,res,ais,rei,aai,ret,ait
          pmag = sqrt(ret**2+ait**2+1.e-12)
          spl = 20.*alog10(pmag/pref)
          write(10,*)zz,rr,spl,ret
          enddo
C
C*****
C End postprocessing for Example 1
C*****
C
C-----
C Example 2: Lined inlet with one segment
C-----
C
      NL = 1
      Zliner(1) = 0.0
      Zliner(2) = 0.4
      admit(1) = cmplx(1.,-1.)
      rewind(9)
      call TBIEM3D(kspin,ident,outfile,nharm,nblades,rpm,radiusd,
1          zte,zle,radius0,thrustc,sposnd,density,V,NL,
2          Zliner,admit,NOBS,ZOBS,rOBS)
C
C*****
C Begin output for user document graphics
C*****
C
      write(10,*)'zone t = "2", i = ',nr,', j = ',nz
      rewind(9)
      do j = 1,19
          read(9,*)
          enddo
      do iobs = 1,NOBS
          read(9,600)zz,rr,res,ais,rei,aai,ret,ait
          pmag = sqrt(ret**2+ait**2+1.e-12)
          spl = 20.*alog10(pmag/pref)
          write(10,*)zz,rr,spl,ret
          enddo

```

Figure 4 (Continued): Calling Program for TBIEM3D Examples 1-3

```

c
c*****
c End postprocessing for Example 2
c*****
c
c
c-----
c Example 3: Lined exhaust with one segment and lined inlet
c           with one segment
c-----
c
      NL = 2
      Zliner(1) = -0.4
      Zliner(2) = 0.0
      Zliner(3) = 0.4
      admit(1) = cmplx(.5,0.)
      admit(2) = cmplx(1.,-1.)
      rewind(9)
      call TBIEM3D(kspin,ident,outfile,nharm,nblades,rpm,radiusd,
1             zte,zle,radius0,thrustc,sposnd,density,V,NL,
2             Zliner,admit,NOBS,ZOBS,rOBS)
c
c*****
c Begin output for user document graphics
c*****
c
      write(10,*)'zone t = "3", i = ',nr,', j = ',nz
      rewind(9)
      do j = 1,19
        read(9,*)
      enddo
      do iobs = 1,NOBS
        read(9,600)zz,rr,res,ais,rei,aii,ret,ait
        pmag = sqrt(ret**2+ait**2+1.e-12)
        spl = 20.*alog10(pmag/pref)
        write(10,*)zz,rr,spl,ret
      enddo
c
c*****
c End postprocessing for Example 3
c*****
c
      stop
600  format(8e11.4)
      end

```

Figure 4 (Continued): Calling Program for TBIEM3D Examples 1-3

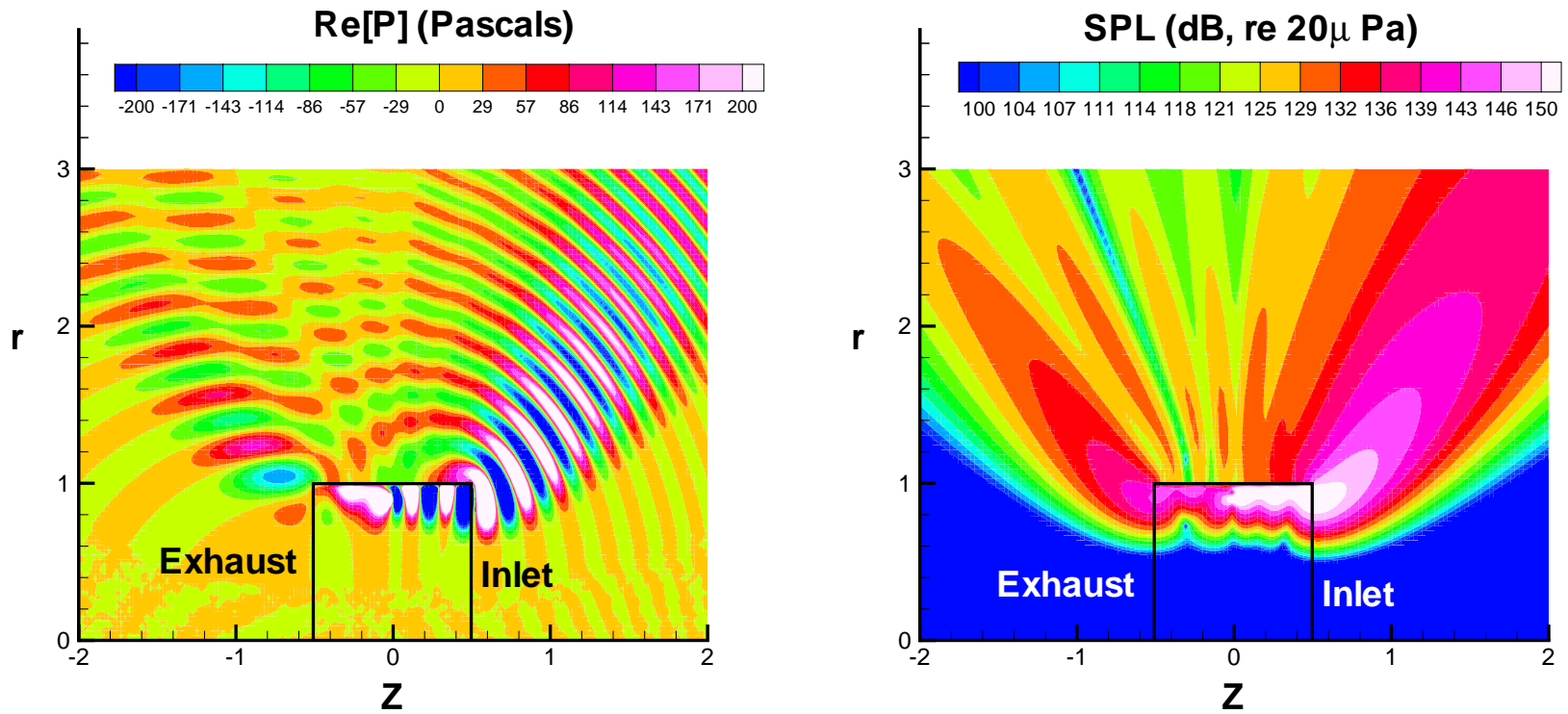


Figure 5: TBIEM3D Example #1 - Hard Inlet and Hard Exhaust
Spinning Point Dipole Sources

$$\begin{aligned}
 &M_F = 0.40 \quad M_{TIP} = 1.22 \quad L_D = 0.5 \\
 &m = 1 \quad N_B = 20 \quad r_D = 1.0 \text{ m} \quad r_0 = 0.9 \text{ m} \quad T = 1.0 \text{ kN}
 \end{aligned}$$

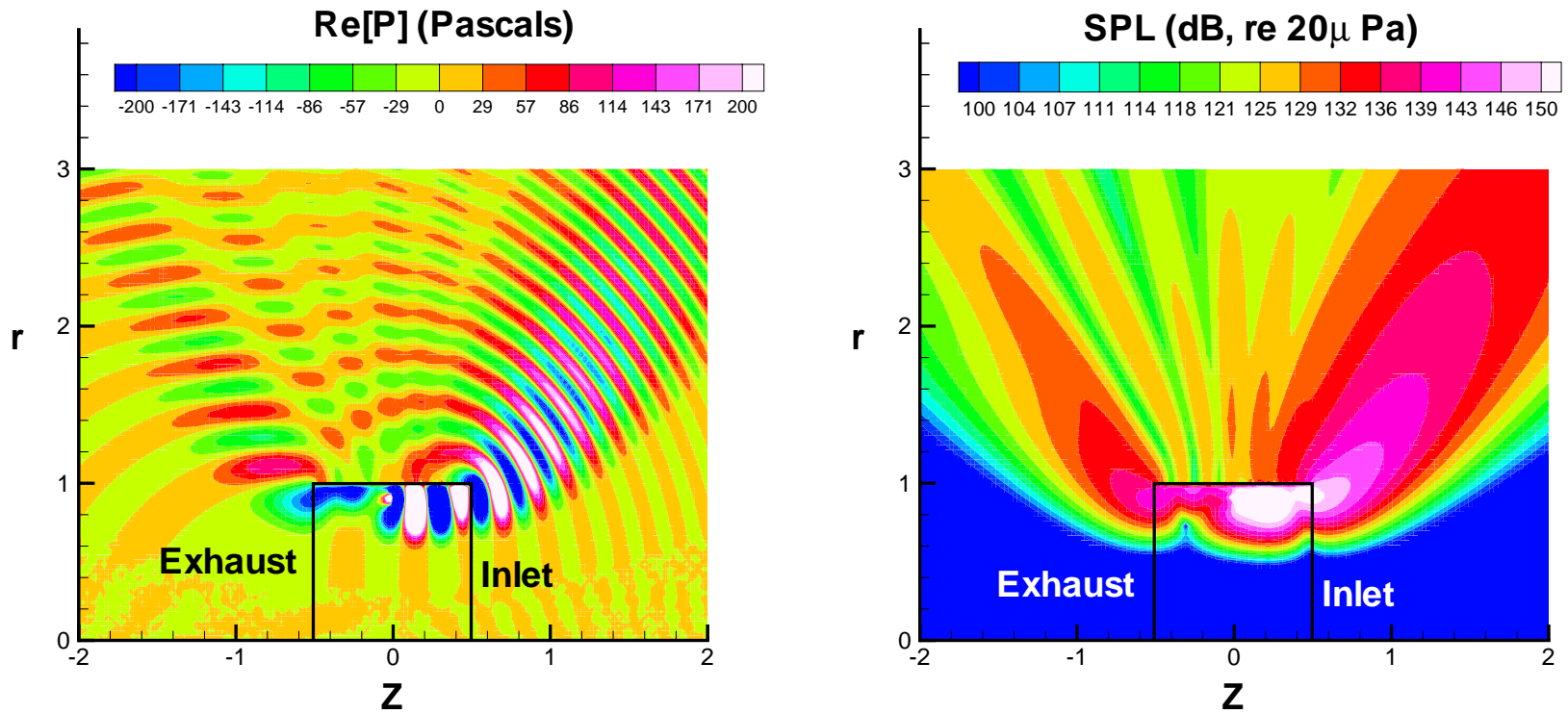


Figure 6: TBIEM3D Example #2 - Lined Inlet and Hard Exhaust
Spinning Point Dipole Sources

$$\begin{aligned}
 &M_F = 0.40 \quad M_{\text{TIP}} = 1.22 \quad L_D = 0.5 \\
 &m = 1 \quad N_B = 20 \quad r_D = 1.0 \text{ m} \quad r_0 = 0.9 \text{ m} \quad T = 1.0 \text{ kN}
 \end{aligned}$$

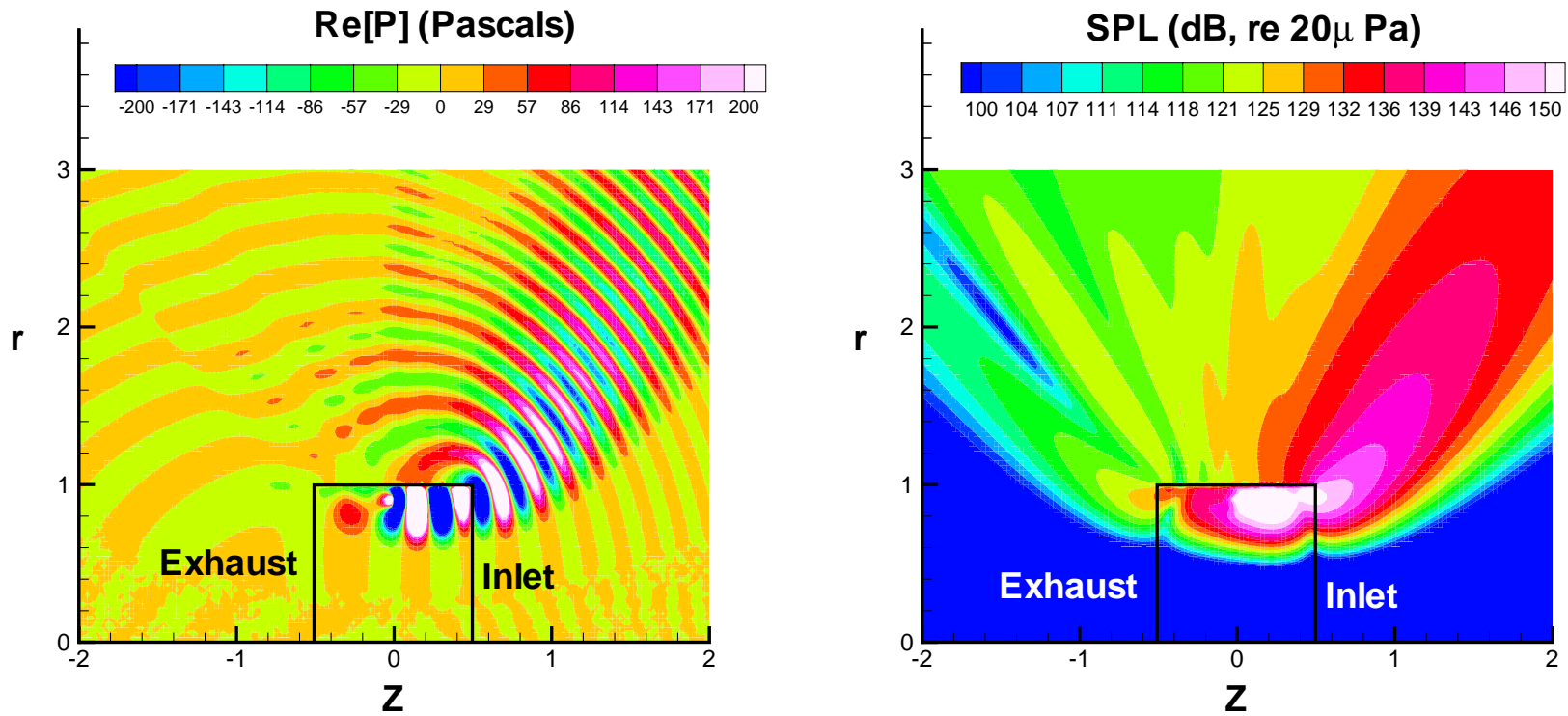
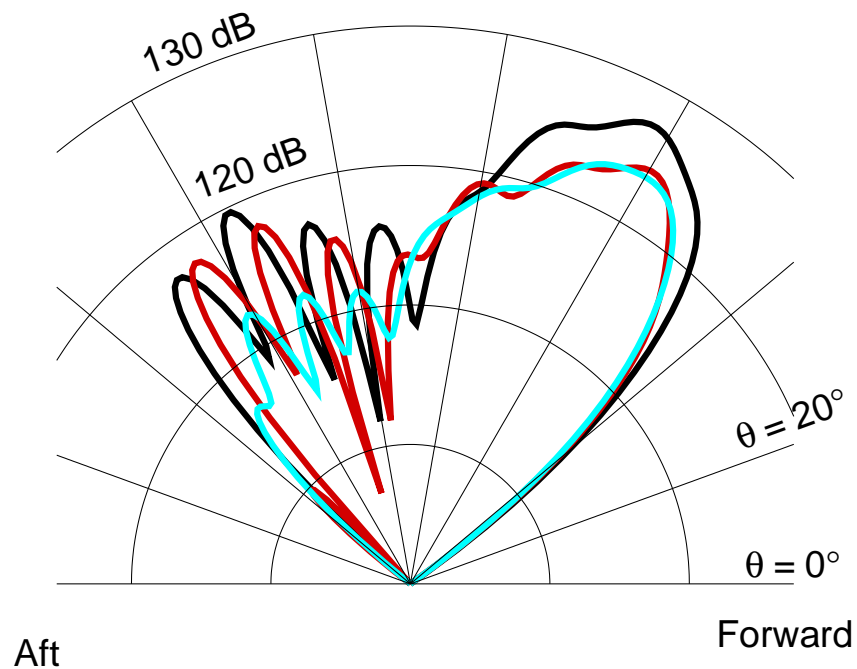
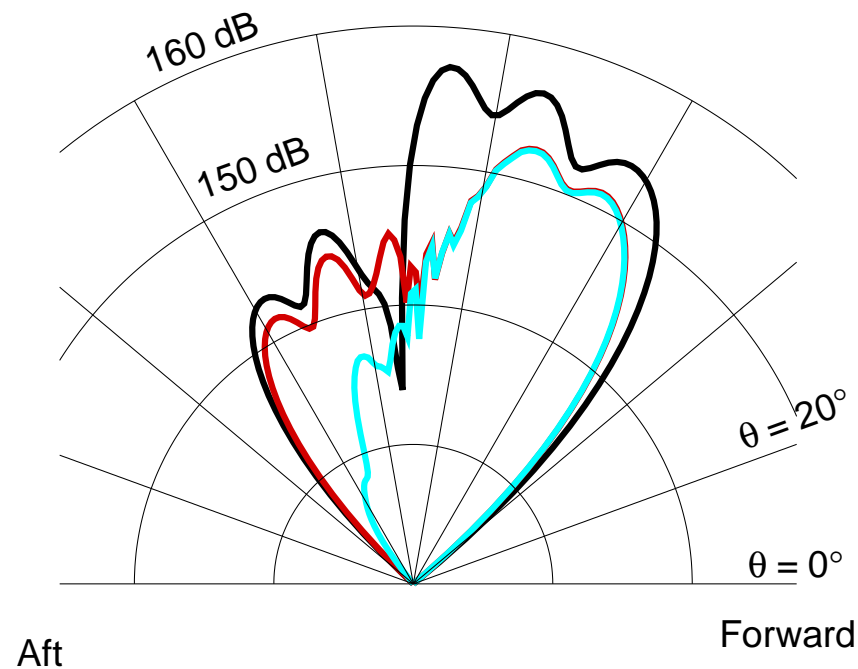


Figure 7: TBIEM3D Example #3 - Lined Inlet and Lined Exhaust
 Spinning Point Dipole Sources

$$\begin{aligned}
 &M_F = 0.40 \quad M_{TIP} = 1.22 \quad L_D = 0.5 \\
 &m = 1 \quad N_B = 20 \quad r_D = 1.0 \text{ m} \quad r_0 = 0.9 \text{ m} \quad T = 1.0 \text{ kN}
 \end{aligned}$$



Farfield: $R_{\text{OBS}} = 10$ meters



Nearfield: $R_{\text{OBS}} = 1$ meter

- Hard Inlet and Hard Exhaust
- Lined Inlet and Hard Exhaust
- Lined Inlet and Lined Exhaust

Figure 8: Effect of Lined Interior on Radiated Sound
Spinning Point Dipole Sources

$$\begin{aligned}
 &M_F = 0.4 \quad M_{\text{TIP}} = 1.22 \quad L_D = 0.5 \\
 &m = 1 \quad N_B = 20 \quad r_D = 1.0 \text{ m} \quad r_0 = 0.9 \text{ m} \quad T = 1.0 \text{ kN}
 \end{aligned}$$

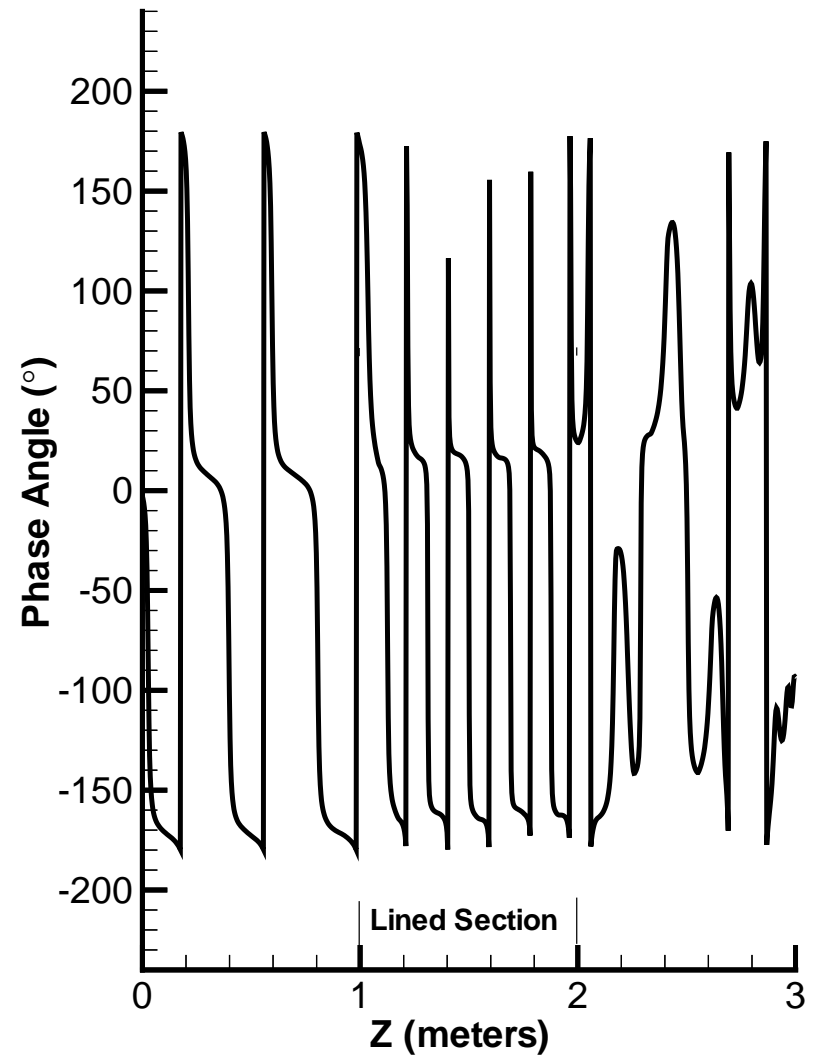
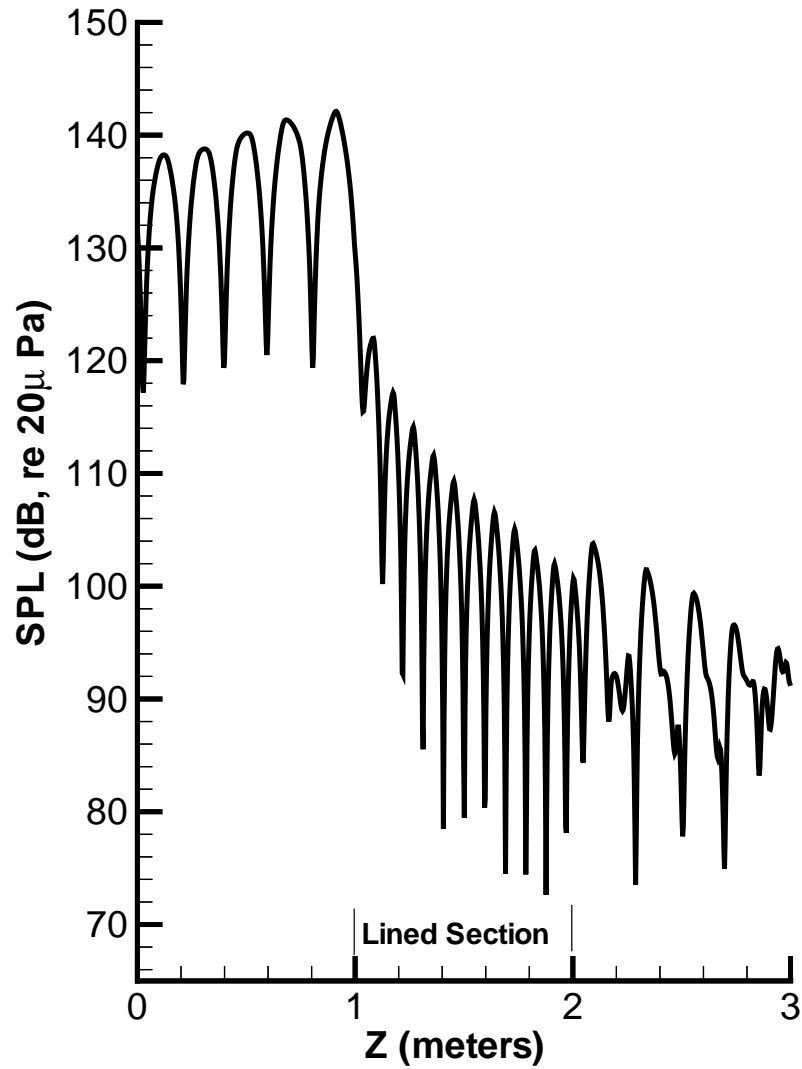


Figure 9: TBIEM3D Example #4 - Impedance Tube Simulation

$$m = 0 \quad r_D = 0.0254 \text{ m} \quad M_F = 0.0 \quad \alpha = 2.2 + 0.2 i \quad \omega = 900 \text{ Hz}$$

TBIEM3D History

- 1) May 15, 1997: Version 1 released
- 2) July 18, 1997: Version 1.1 released; Version 1 errors corrected; nonspinning point dipole sources added to accommodate zero-th circumferential mode; User manual modified; Example 4 (Figure 9) added; **Version 1 no longer supported**

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13. ABSTRACT (Maximum 200 words) This document describes the usage of the ducted fan noise prediction program TBIEM3D (Thin duct - Boundary Integral Equation Method - 3 Dimensional). A scattering approach is adopted in which the acoustic pressure field is split into known incident and unknown scattered parts. The scattering of fan-generated noise by a finite length circular cylinder in a uniform flow field is considered. The fan noise is modeled by a collection of spinning point thrust dipoles. The program, based on a Boundary Integral Equation Method (BIEM), calculates circumferential modal coefficients of the acoustic pressure at user-specified field locations. The duct interior can be of the hard wall type or lined. The duct liner is axisymmetric, locally reactive, and can be uniform or axially segmented. TBIEM3D is written in the FORTRAN programming language. Input to TBIEM3D is minimal and consists of geometric and kinematic parameters. Discretization and numerical parameters are determined automatically by the code. Several examples are presented to demonstrate TBIEM3D capabilities.				
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